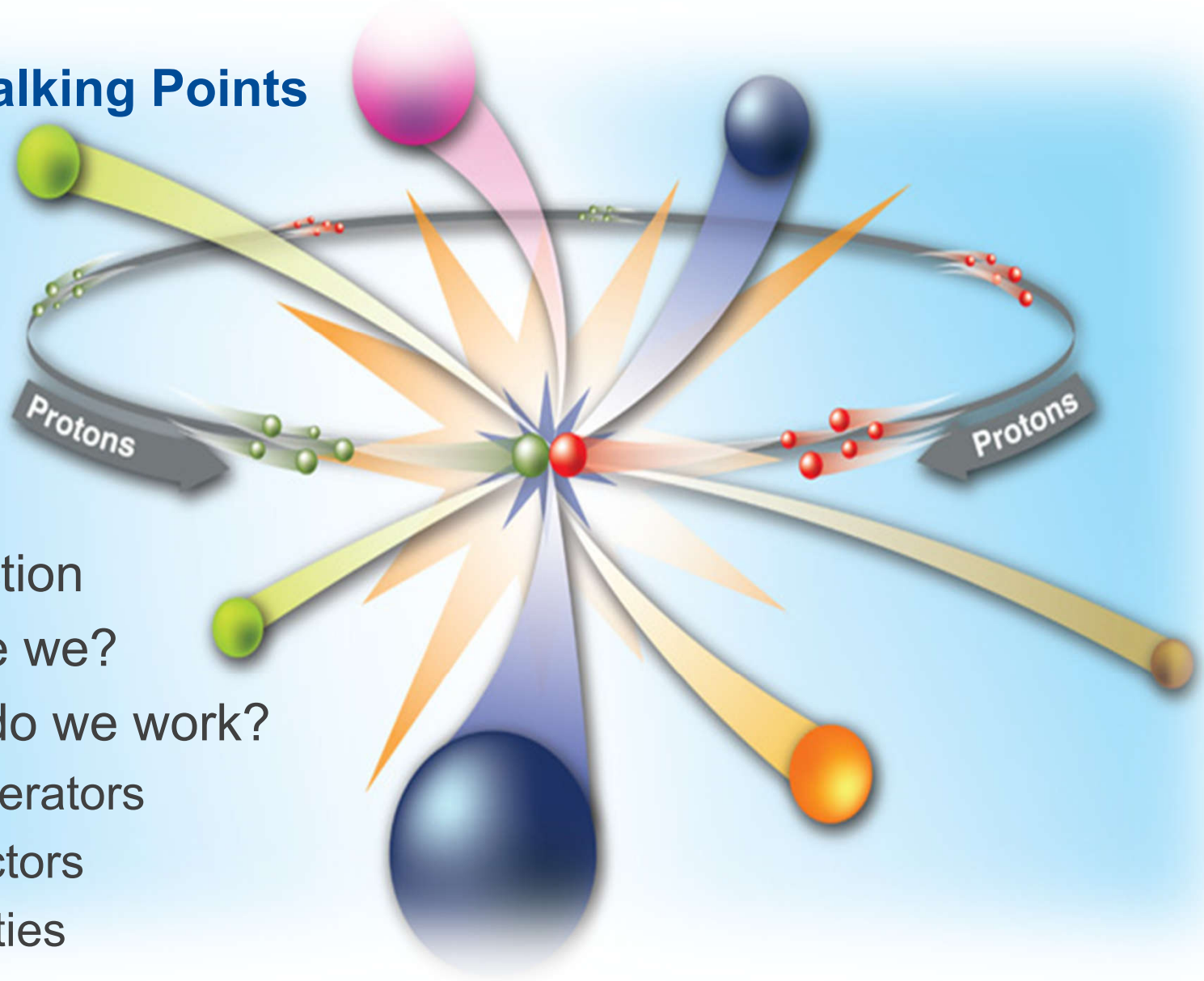
Engineering at Fermilab

Mayling Wong-Squires

Ask-An-Engineer

1 March 2020

Today's Talking Points

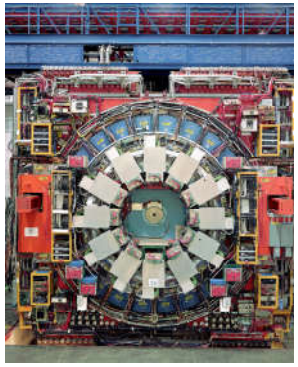


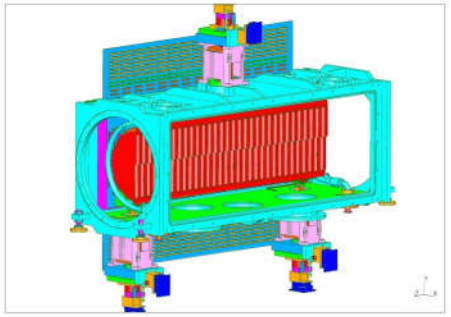
- Introduction
- Who are we?
- Where do we work?
  - Accelerators
  - Detectors
  - Facilities
  - Projects

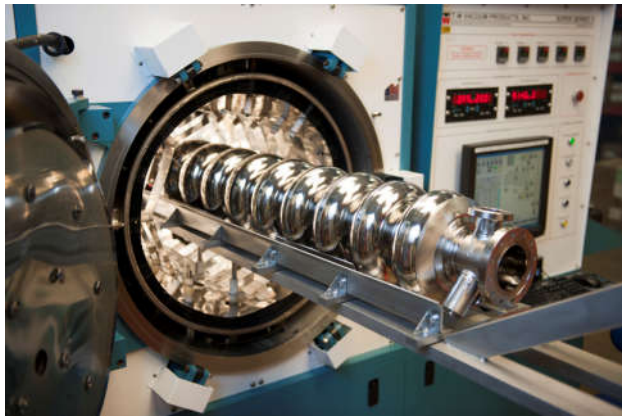
About me

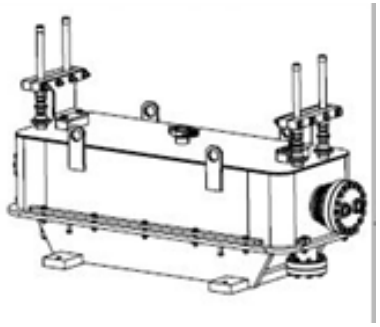
- Mechanical Engineer at the lab for 23-years
- My roles
  - Head of AD/Mechanical Support Department
    - 70+ personnel
    - Mechanical engineers, design/drafters, technicians
    - Provide vacuum, structural and fluids support to accelerator complex
  - Co-chair of the Engineering Promotion Committee
  - Member of the Cryogenic Safety Subcommittee for the Test Facilities
  - Member of Fermilab Society of Women Engineers (fSWE)

Some projects from the past 20+ years








- Flammable gas system for a detector
- Installation of 5-ton to 20-ton magnets on a sloped surface without a crane
- Optimizing the vacuum pumping for a pixel detector
- Vacuum furnace heat treatment to degas SRF cavities
- Vacuum vessel design of a cryomodule
- Vacuum design of a dipole magnet containing ferrites

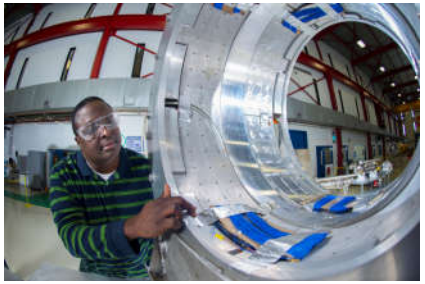
Introduction to Engineers at Fermilab

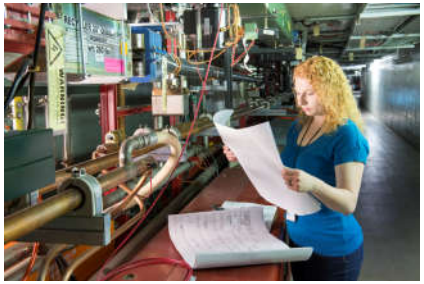
Engineers at Fermilab are essential to its vision, which is to solve the mysteries of matter, space and time for the benefit of all.

- Unique and challenging projects
- Diverse set of design problems
- Special solutions

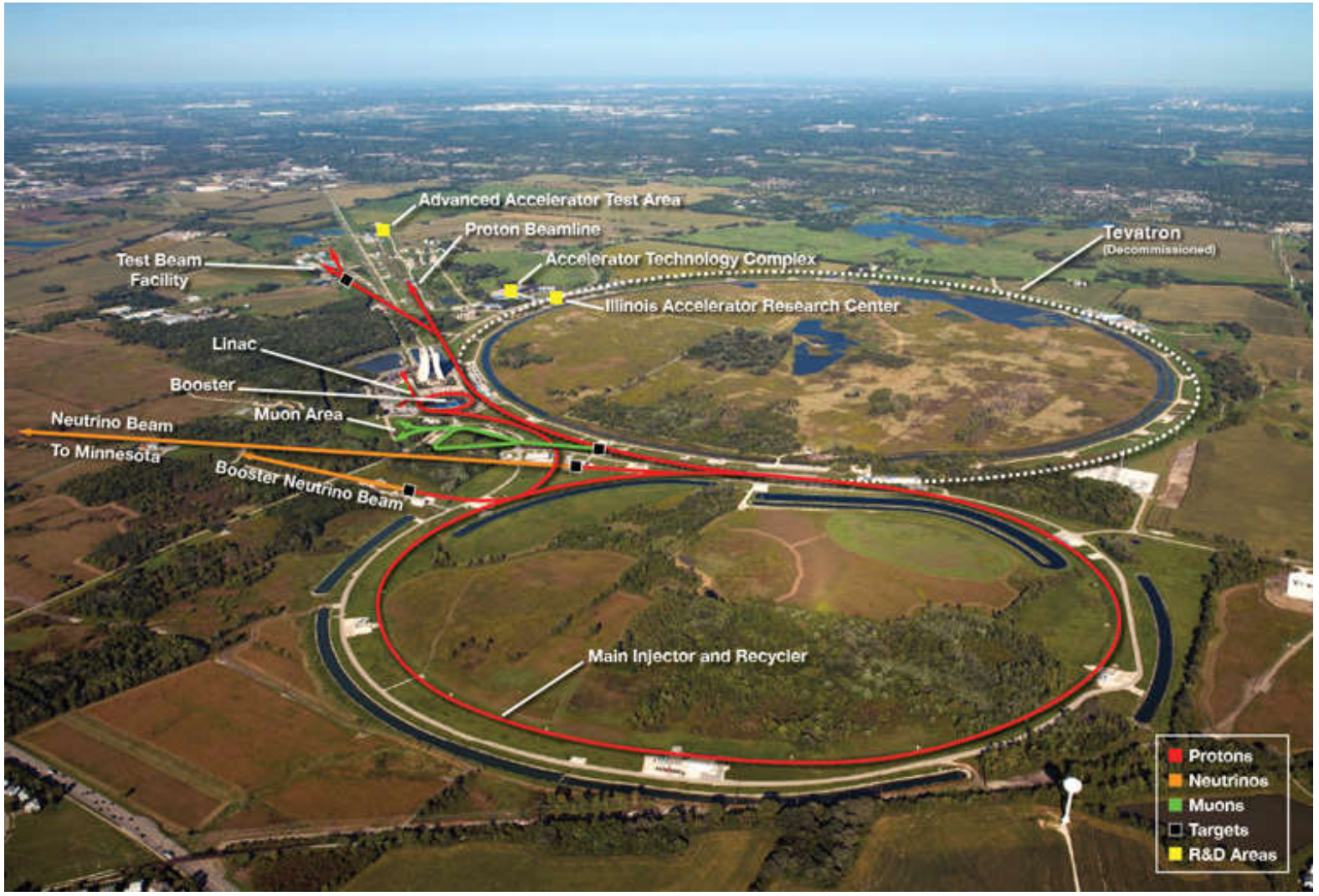
Who are we?

- Part of a team that also includes scientists, technicians, drafters, contractors
- 243 engineers (14% of lab employees)
  - Civil Engineers
  - Electrical Engineers
  - Mechanical Engineers
- Computer engineers / professionals

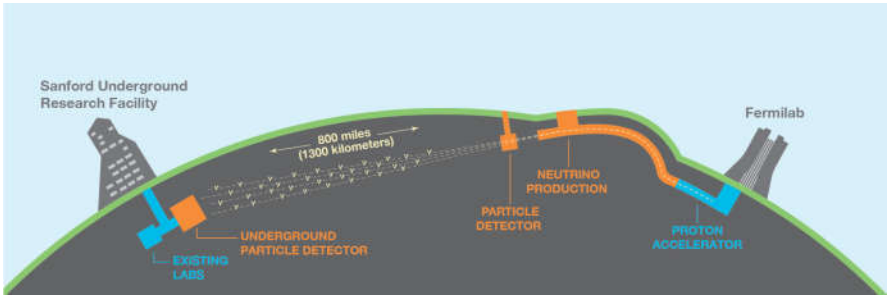




Where do we work? Main Campus – Batavia, IL



Remote sites: Leads, SD and Ash River, MN

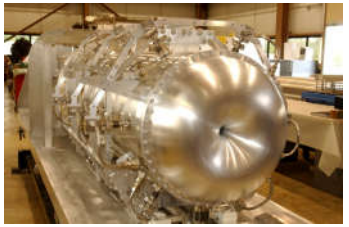


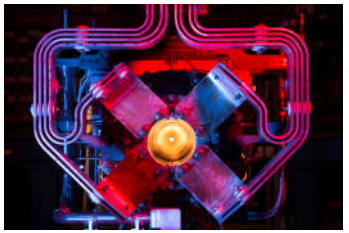
Deep Underground Neutrino Experiment (DUNE)

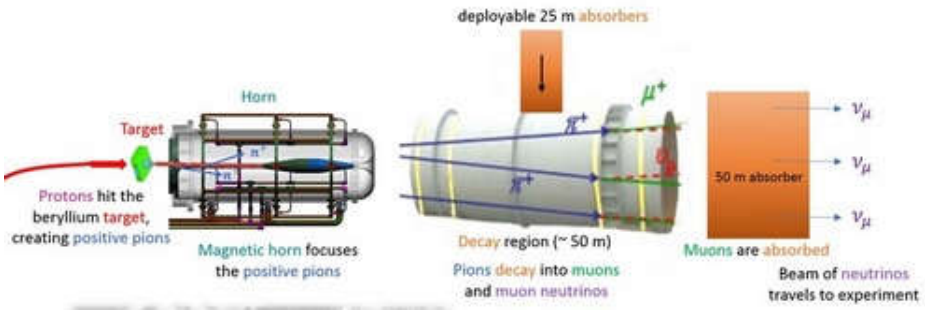
NoVA Experiment

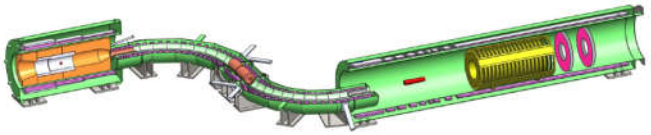
What does it take to study sub-atomic particles?

- Accelerate a beam of protons
  - Electromagnets and radio-frequency cavities to accelerate and position the beam
  - Instrumentation to “see” the beam
- Create new particles
  - Neutrino or muon beam
  - Target, horn, decay region and absorber
- Send particles to detector to study
  - Neutrino detectors using liquid argon
  - Muon experiments
    - Study muons in a high magnetic field (g-2)
    - Do muons convert to electrons? (Mu2e)



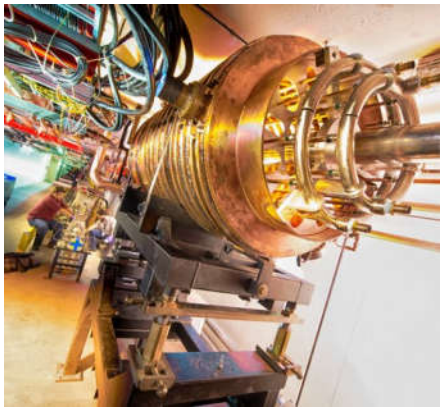






Accelerator Components

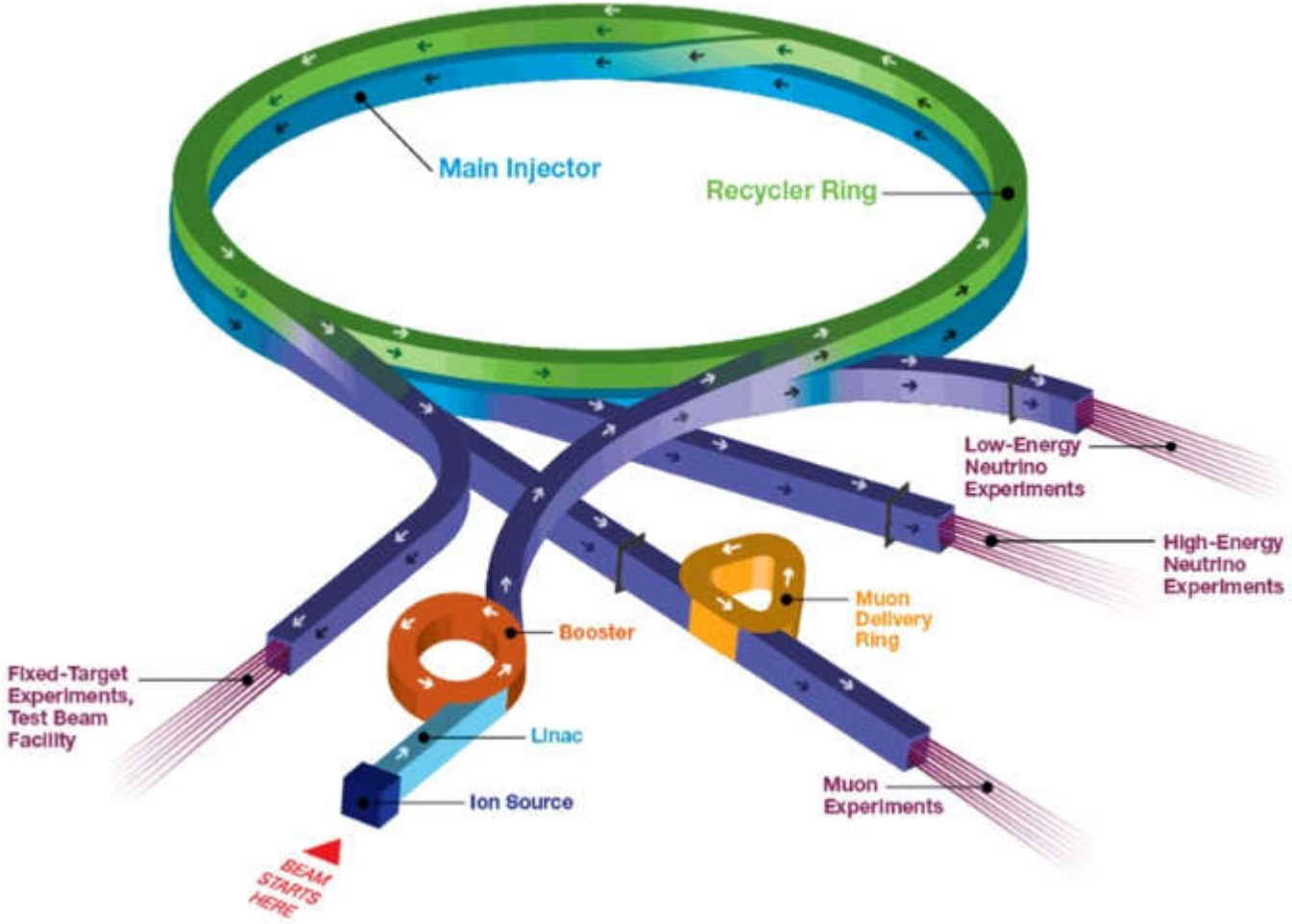
Sextupole magnet during assembly and completed



High powered
radio frequency cavity
2.5MHz to 1.3 GHz
(cell phone systems 2 GHz)

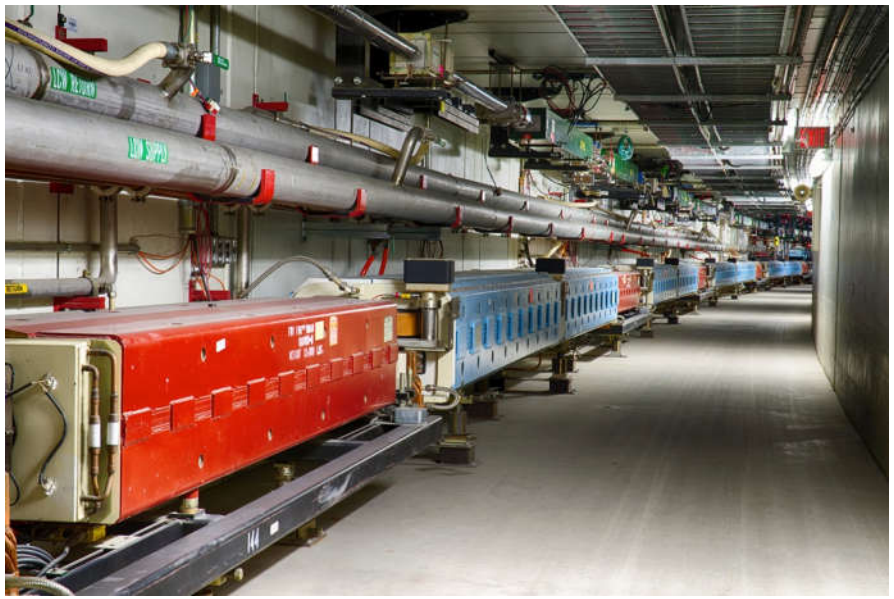
- Conventional electromagnets
  - Copper conductor
  - Water cooled
- Superconducting magnets
  - Niobium-tin or niobium-titanium coils
  - Cooled to 4°K with liquid helium
- Radio frequency cavities
  - Water cooled, copper
  - Superconducting, niobium (future)
- Areas of expertise
  - Electrical engineering
    - Magnet power
    - Magnetic measurements
    - Controls for data acquisition
  - Mechanical engineering
    - Materials study
    - Thermal analysis
    - Mechanical design
    - Vacuum design
    - Cryogenics

Accelerator Complex



Fermilab

Engineering in an Accelerator



Main Injector / Recycler Accelerator

- Cooling fluid
  - Low conductivity water
  - Cooling capacity in the megawatts
  - Operating temperature 90°F
  - Compare to a typical residential AC unit 10-kW
- Vacuum beampipe
  - Pipe diameter 6-inches
  - Vacuum pressure $1x10^{-8}$ torr
  - Comparisons
    - 730 torr at atmospheric pressure
    - 10^{-12} torr in outer space
- Mechanical support
  - Magnet weight 100 to 40,000 pounds
  - Align to position 0.005-inches
  - Consider position
    - Support off the ground
    - Hang from ceiling
    - Hang from the wall
- Power supplies
  - 2000 power supplies for the entire accelerator
  - Total capacity of over 240 MVA
  - Comparison: typical computer power supply 0.0001 MVA

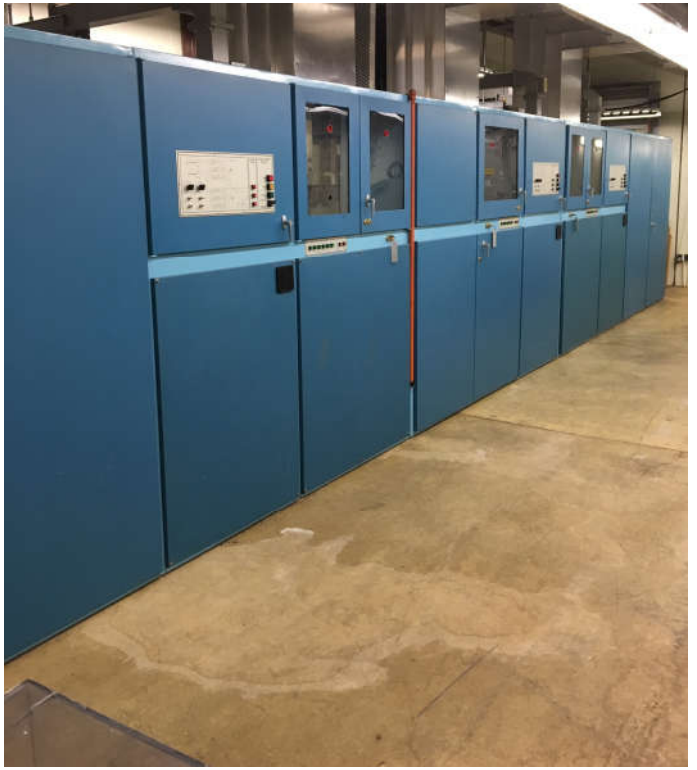
Mechanical engineer
- Fluid and process engineering
- Thermal analysis
- Structural design
  - 3D printing
- Vacuum engineer

Electrical engineer
- Power
- Radio frequency
- Instrumentation

Main Injector Power Supply - 6 sets

Transformer outside of a service building

- **800-V AC**
- **4000-A AC**

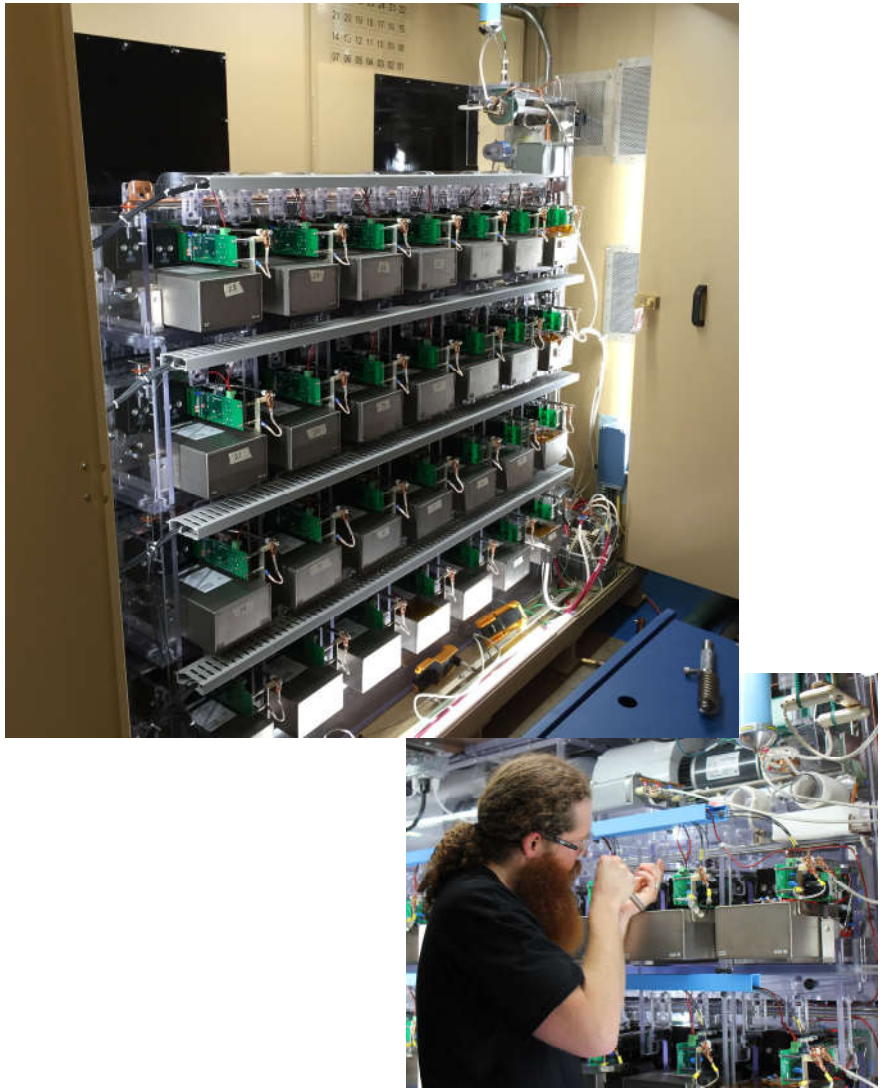


Rectifier inside a service building

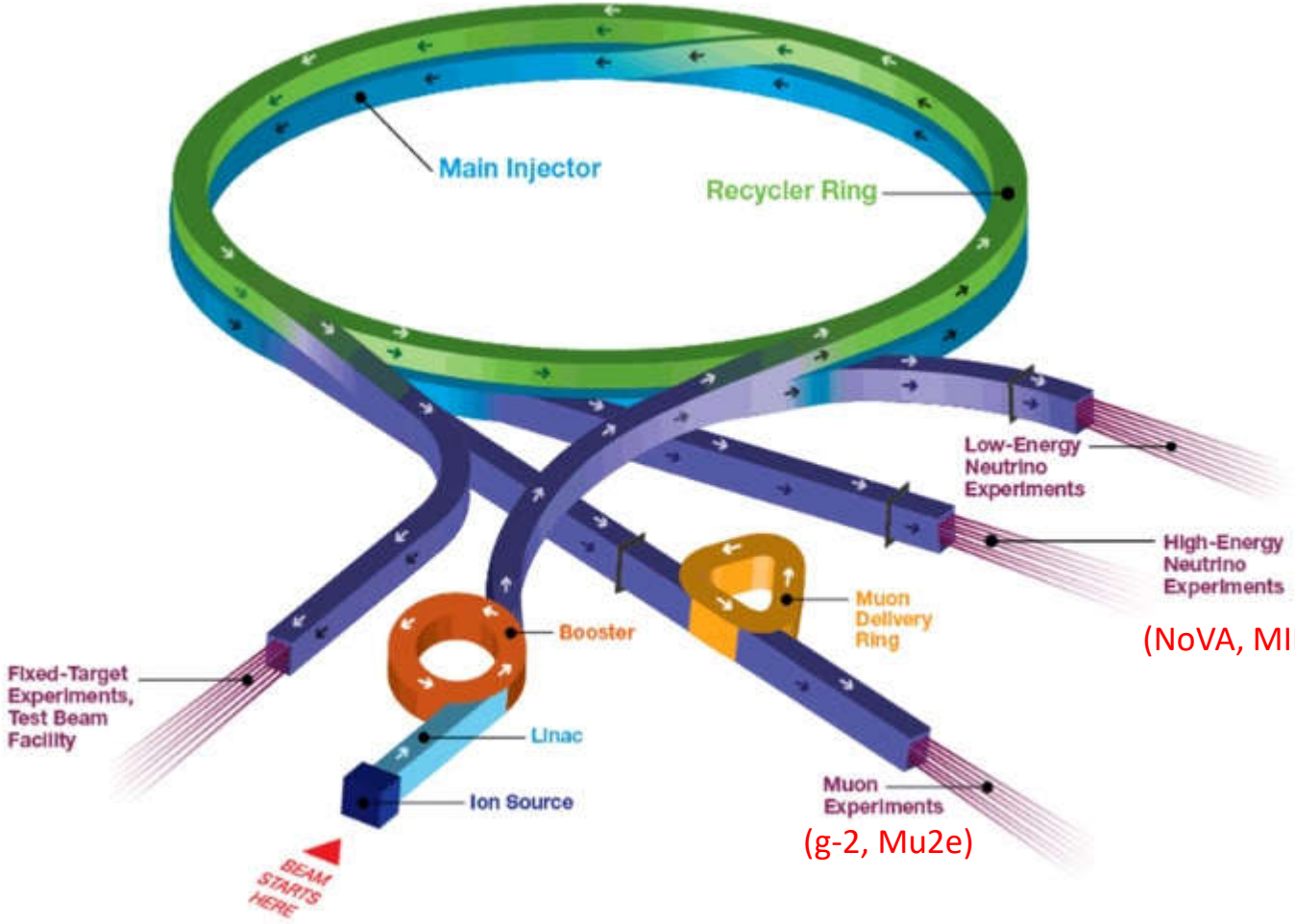
- **Converts AC to 1000-V DC**
- **10,000-A DC**
- **Total capacity per building 10 MVA**

Marx Modulators for Linac RF Cavities

- Custom-built system that provides 30-kV, 300-A to the power amplifier
  - Power amplifier supplies power to the RF cavities to accelerate beam
- Charges capacitors to give a large voltage drop
  - The more capacitors, the larger the voltage drop
  - An analogy: the more battery power, the brighter the flashlight



Provide Beam to Experiments On-Site and Off-Site

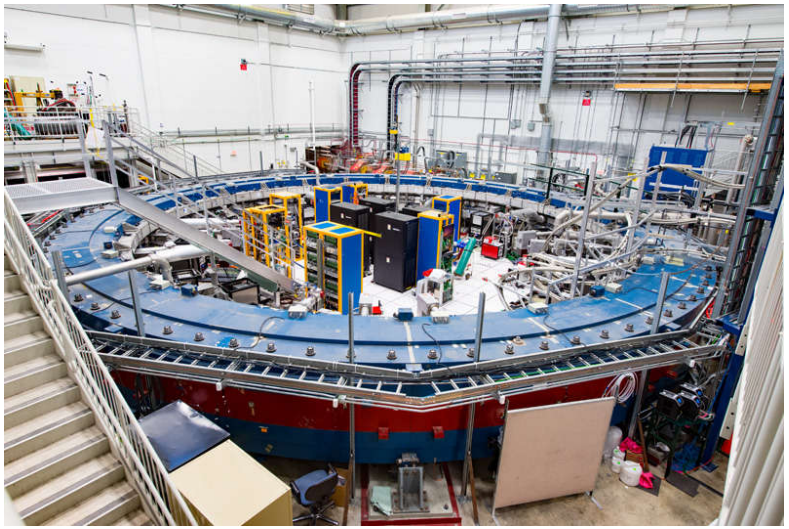


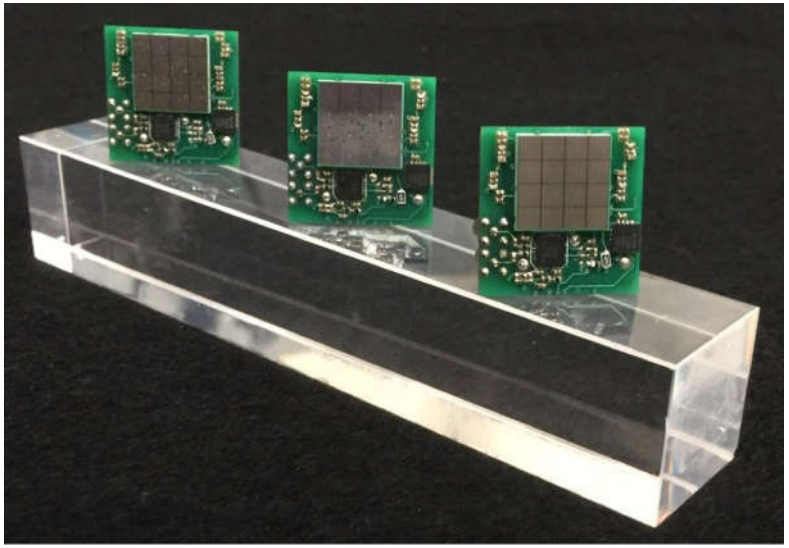
(Short-Baseline Neutrino, MicroBooNE)

(NoVA, MINOS)

(g-2, Mu2e)

Send beam to a muon experiment



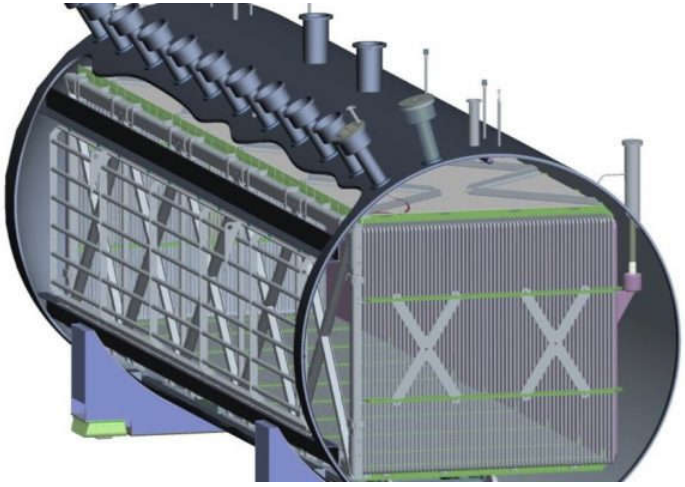


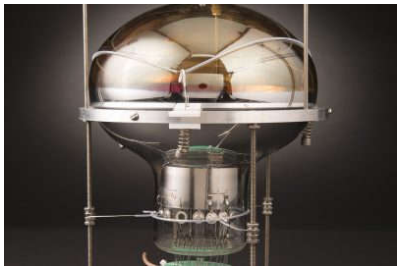
- Muon g-2
  - 50-foot diameter superconducting electromagnet
  - Study the “wobble” of the muon beam when placed in the magnetic field
  - Detectors to measure muon energy and decay time (calorimeter)
- Electrical engineers
  - Design, manufacture, install detectors
  - Control system
- Mechanical engineers
  - Cryogenic system – liquid helium
  - Transport and install electromagnet that from Brookhaven National Laboratory (NY)

Send beam to an on-site neutrino experiment

- MicroBooNE
  - Send neutrino beam to a target made of liquid argon
  - Detector made of wire planes to record ionized electrons that emerge from LAr
  - Array of photomultiplier tubes measure the scintillating light of the ionized particles

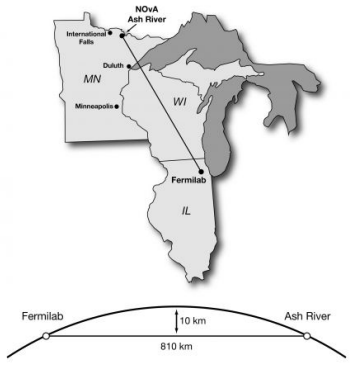
MicroBooNE cryostat containing 170-tons of liquid argon time projection chamber (wire planes)





Send beam to an off-site experiment

NoVA 14-kiloton far detector comprised of liquid scintillator



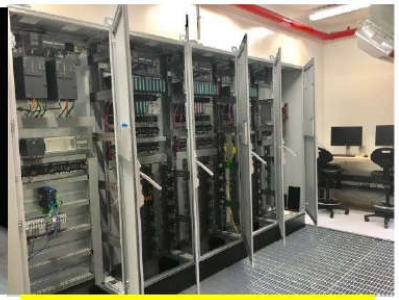
Highly reflective plastic extruded tubing 15.5-m long. Inside the detector, the tubing will be filled 2.7-million gallons scintillating oil

- Study of neutrino interaction
- NuMI
  - Create neutrino beam here at the main campus
  - "Near" detector to characterize the neutrinos at Fermilab
- NoVA and MINOS
  - Ash River, MN
  - Bottom of a former iron mine (Soudan mine) located 2341-ft below the surface
  - "Far" detector to characterize neutrinos after 810-km travel

Send beam to future on-site experiment

Cryo Supply for LAr and LN2

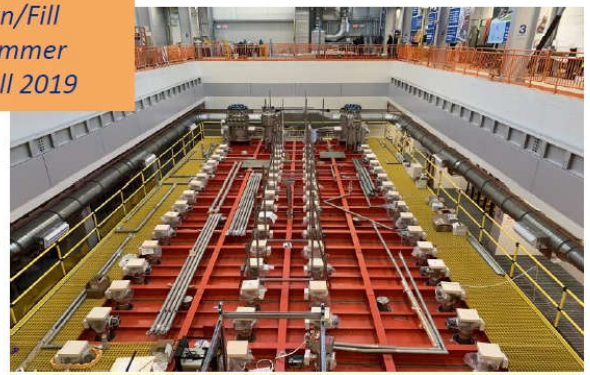
CERN Deliverable of argon Cryogenics



PLC Based Process Controls

Anticipate Cooldown/Fill in late summer or early fall 2019

Rigging of One of Two Cold Vessels for ICARUS into Warm Outer Vessel

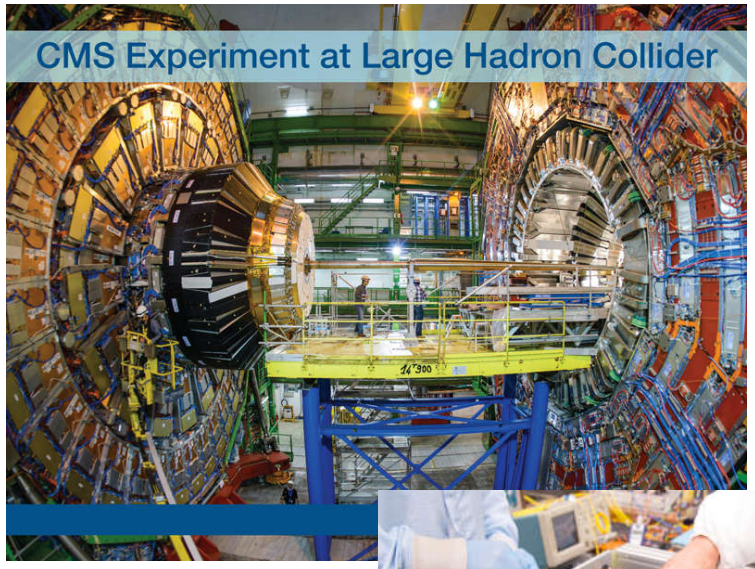


Enclosed Cold Vessels in Warm Vessel (red) Chimneys/Feedthroughs in Roof (shown)

Short-Baseline Neutrino Program – Far Detector (ICARUS)

- **Filled with liquid argon (~80°K)**
  - 2 detectors
  - Each detector holds 300 tons LAr (170,000 gallons or 32 tankers)
  - Chamber modules and photodetectors to detect neutrino interaction with argon
- **Electrical, mechanical, cryogenic engineers**
  - Readout electronics
  - LAr cryogenic system
  - Mechanical installation

Support experiments and projects at other organizations



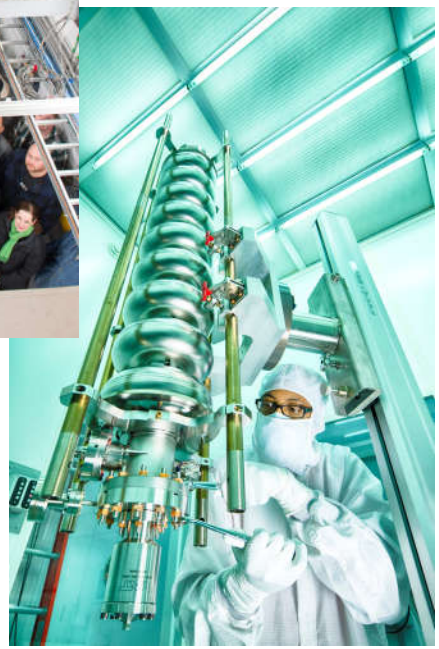
Quarter-section of the CMS Forward Pixel (FPIX) Detector Upgrade, part of LHC at CERN

11-Tesla dipole test magnet for the LHC High Lumi upgrade at CERN

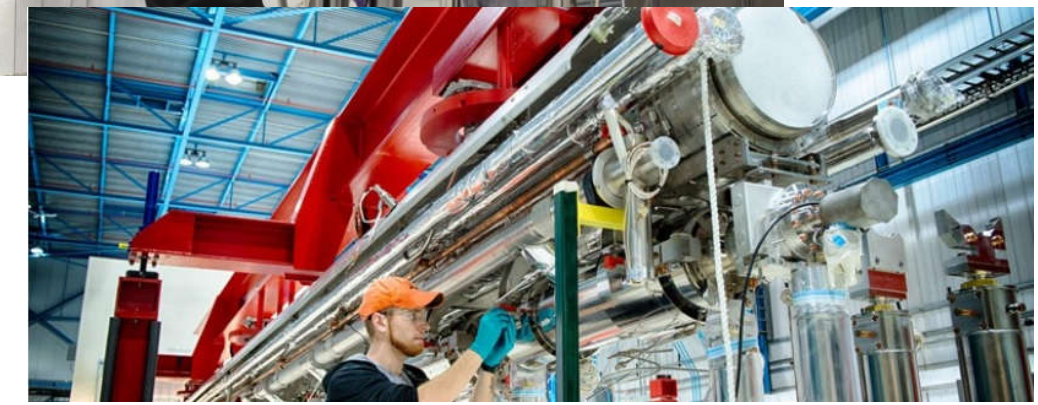
- CERN – particle physics laboratory in Geneva, Switzerland
  - Particle / particle collisions
- Forward Pixel Detector upgrade for Compact Muon Solenoid
  - Silicon detectors located near the collision location
  - Carbon fiber provides mechanical support to minimize particle interaction
- Large Hadron Collider (LHC) High Luminosity Upgrade
  - Design and fabricate 11-Tesla dipole magnet
  - Superconducting coils made of niobium-tin

Support for other projects – LCLS-II

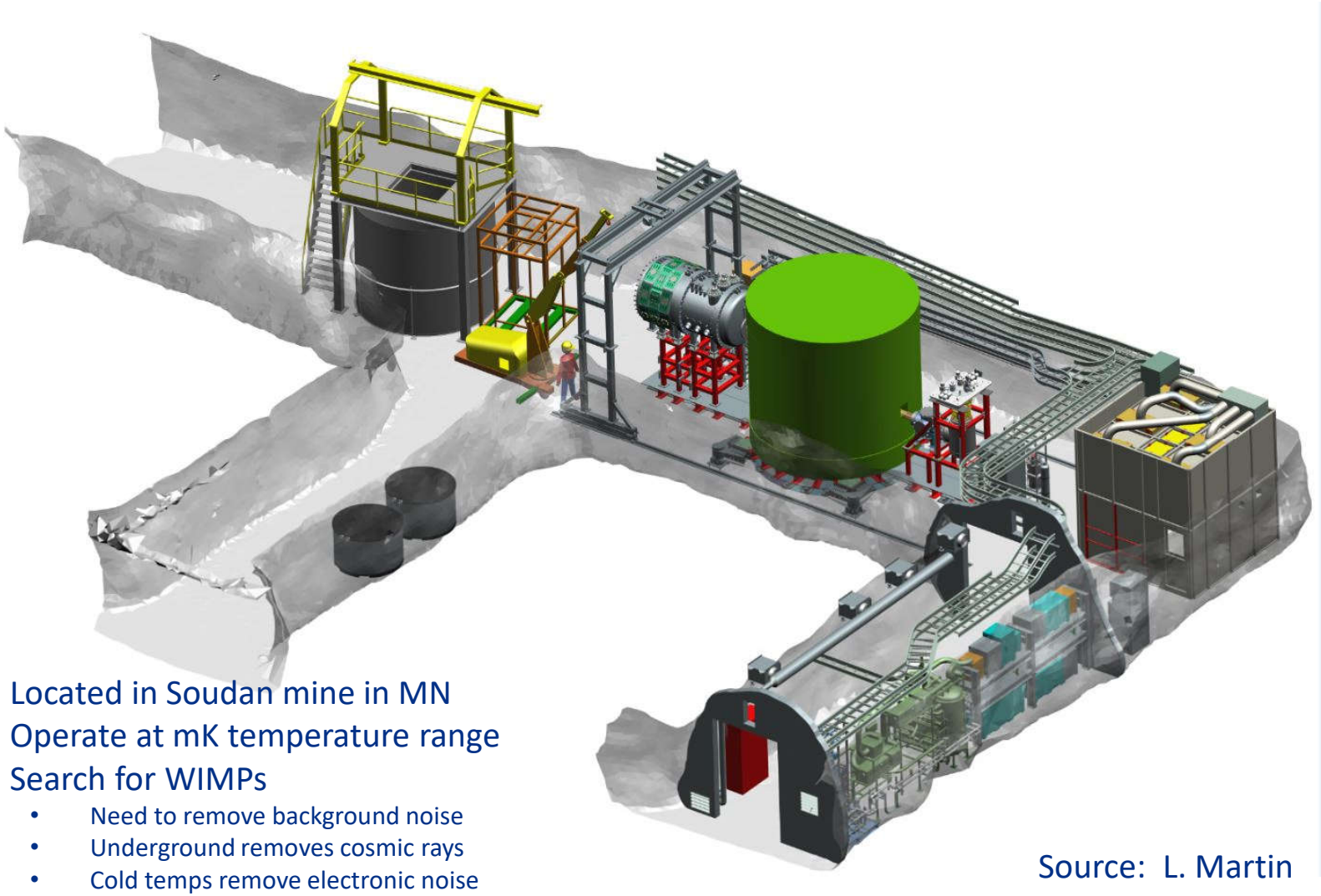
- Linac Coherent Light Source II at Stanford Linear Accelerator Laboratory (SLAC)
- Cryomodule
  - Next generation accelerator component
  - Superconducting radio frequency cavities
    - Niobium and niobium-titanium
    - Operate at 1.8°K
    - Cavity frequencies of 1.3-GHz and 3.9-GHz
    - Record breaking quality factor (Q_0) 2.7×10^{10}



Design, manufacturing, and testing cryomodule and its components



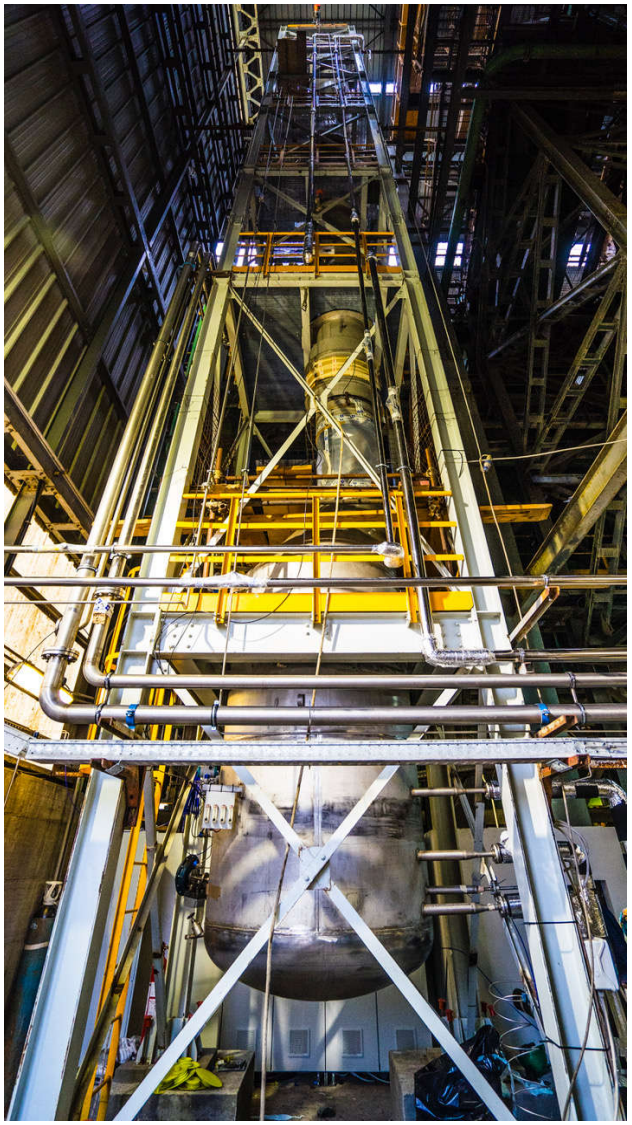
Super Cryogenic Dark Matter Search experiment



- Located in Soudan mine in MN
- Operate at mK temperature range
- Search for WIMPs
  - Need to remove background noise
  - Underground removes cosmic rays
  - Cold temps remove electronic noise

Source: L. Martin

DarkSide LAr Distillation Column installation in Sardinia, Italy



- installation of Seruci 0 (distillation column phase 0)

Source: Cary Kendziora

Engineers for the Facility

Civil, mechanical and electrical engineers for maintenance and upgrades

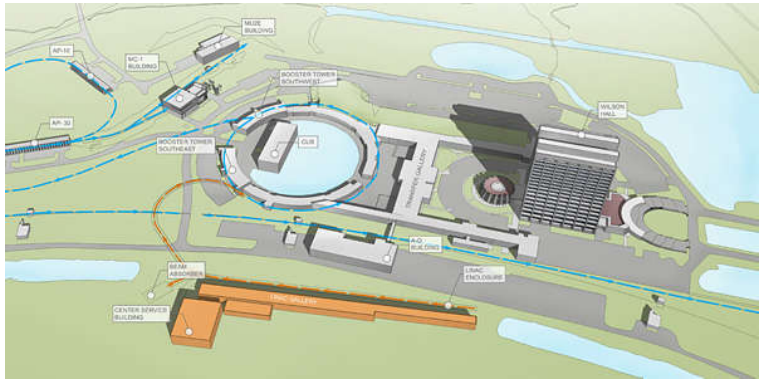
- 6800 acres
  - Same size as O'Hare Airport
- 36 miles of roads
- 112 acres of parking lots
- 366 buildings
  - 2.4 million gross square feet
- 101 miles of electric cable energized through
  - 2 primary electric substations
  - 241 secondary electric substations
- 20 miles of natural gas pipe

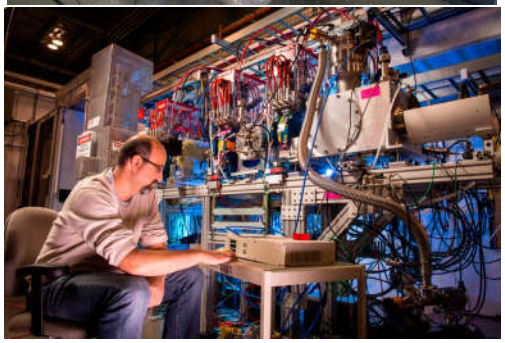
Water at Fermilab

- 24 miles of Industrial Cooling Water pipe and conveyances
  - Provide water for cooling systems of accelerators and detectors
  - Fire protection
  - HVAC cooling
  - 97 million gallons annually
    - Recovered from NuMI/MINOS underground halls
    - Warrenville (well water)
    - Deep well water
- 20 miles of domestic (drinking) water pipe
  - 20 million gallons annually
- Compare: City of Batavia pumped 1.2 billion gallons of water to its users in 2007

Projects for Future Research

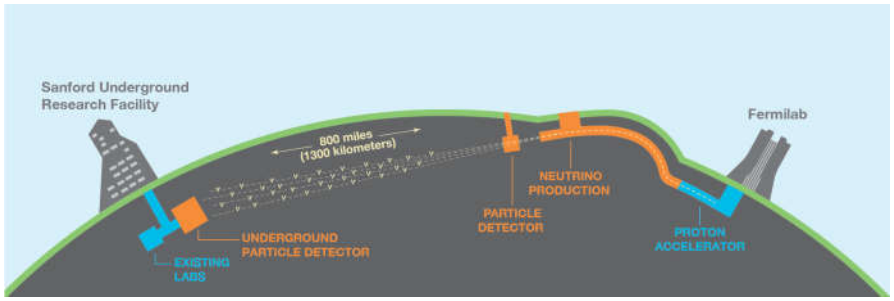
Proton Improvement Plan II (PIP-II)

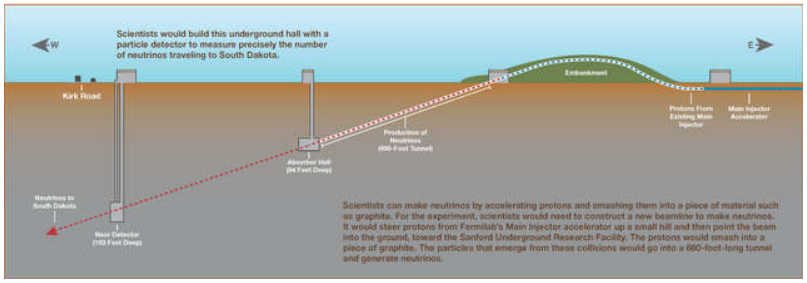


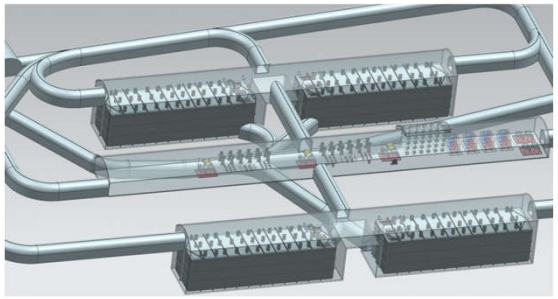


PIP-II will supply a 800-MeV proton beam accelerated at 8-GeV. The beamline will use the next generation superconducting radio frequency cavities. This provides the protons that will create the most intense neutrino beam for LBNF. While construction is not scheduled until 2021, a test beam is being operated with the plan to move it and make it a part of the new beamline.

Long Baseline Neutrino Facility (LBNF) / Deep Underground Neutrino Experiment (DUNE)





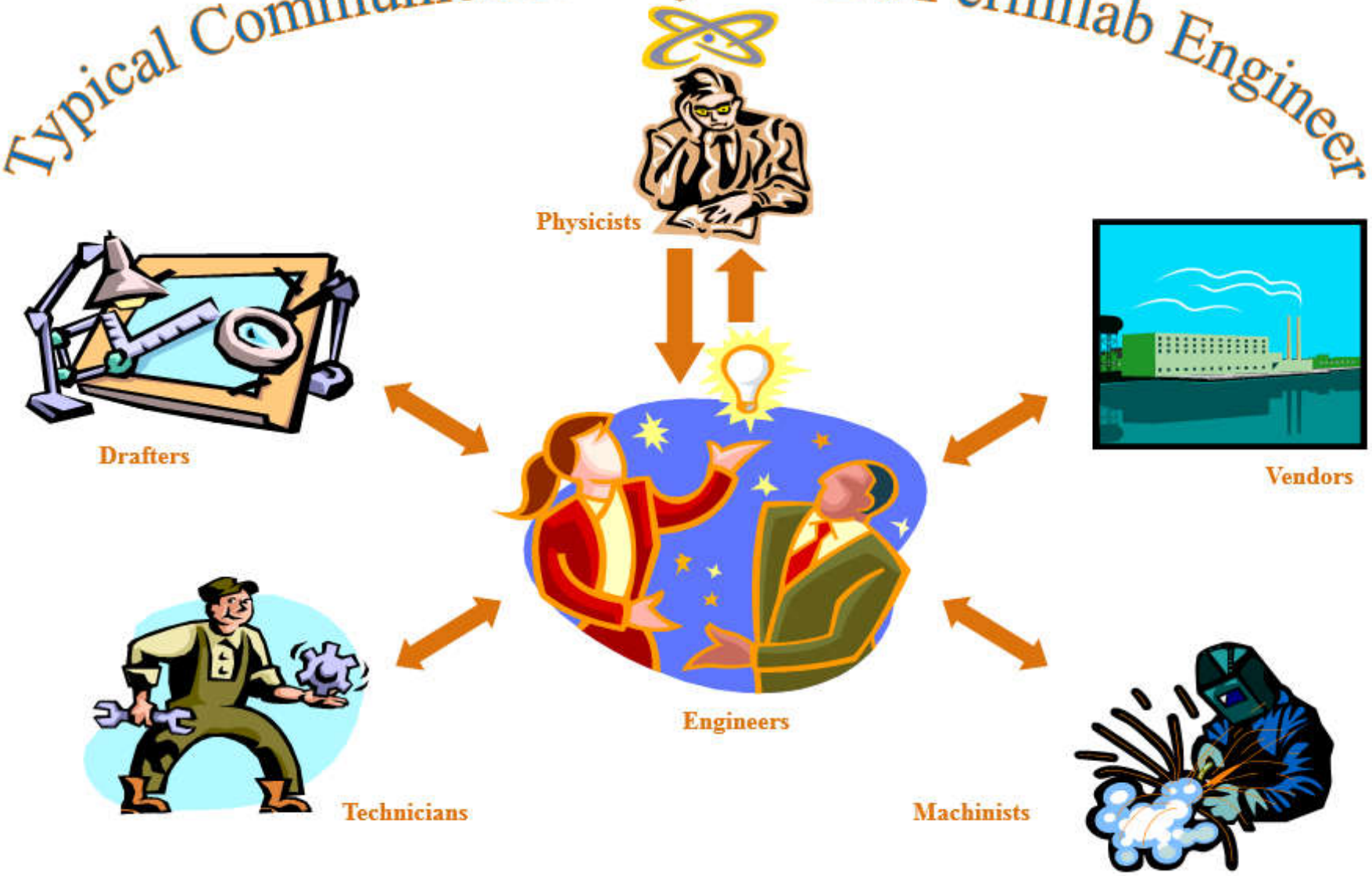


Neutrino research from the LBNF/ DUNE project will make use of the most intense neutrino beam. At DUNE, there will be 4 detector modules, each filled with 17,000-tons of LAr. The detectors will sit at 4850-ft below the earth's surface.

Fermilab

Future building – Integrated Engineering Research Center

Typical Communication Cycle of a Fermilab Engineer



Thank you to the contributors

- Martin Bentivengo - FESS
- Paul Czarapata – AD
- Abhishek Deshpande - AD
- Greg Gilbert - FESS
- Dave Harding – APS-TD
- Chris Jensen - AD
- Karen Kosky - FESS
- Lucy Nobrega - AD
- Barry Norris - ND
- Russ Rucinski - PPD